Integrated model for Multi-criteria Supplier Selection and Order Allocation Problem

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Integrated model for Multi-criteria Supplier Selection and Order Allocation Problem

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Integrated model for Multi-criteria Supplier Selection and Order Allocation Problem

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Abstract. This paper discusses an integrated model of selecting suppliers and order allocation for a company that wishes to decide the quantity to be ordered from each supplier on the basis of some qualitative criteria. Since each supplier may have a different performance with respect to these criteria, an integration of analytical hierarchy process and linear program model is proposed to solve the problem in two stages. In the first stage, suppliers are evaluated based on qualitative criteria to consider both tangible and intangible factors in choosing the best suppliers. The output of this stage is the final score of each supplier. In the second stage, a linear programming model is proposed to placing the optimum order quantities among them such that the total final scores of suppliers become maximum. The mathematical programming model is validated through numerical analysis, and the computation result shows that the model is effective and applicable.
Keywords: supplier selection, order allocation, multiple criteria decision making, analytical hierarchy process, linear programming.

1. Introduction

To be able to survive the current business competition, supplier selection process is a very important issue to be well planned. This is because suppliers will not only determine the price of goods or materials needed, but also the time of delivery. In addition to the price and delivery time, supplier selection is generally based on other criteria, such as goods' quality, after-sales service, response to order changes, supplier's financial condition, supplier location, etc. It is clear that the selection of supplier involves multi-criteria, both quantitative and qualitative. Since there are often conflicts between these criteria, supplier selection should be done by aligning both types of criteria.

Based on the ability of suppliers to meet the needs of buyers, supplier selection issues can be categorized into two types of issues [1]. If all buyers ' needs can be met by one supplier, the issue to be resolved is to choose one best supplier based on predefined criteria. If there is no single supplier can fulfill all of the needs of buyers, then the problem to be solved is to select some suppliers and at the same time specifying the number of items to be ordered from the selected supplier, so that the value of purchase can be maximized. Clearly, the second type of problem is more complex than the first one.

Some models and methods of supplier selection and order quantity allocation problem have been developed by many researchers, where mathematical programming models and approaches have been widely used. Among others is integer linear programming model with the objective of maximizing the preference weight of supplier [2], mixed integer programming (MIP) model with various objectives,

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such as minimizing both the cost and the number of suppliers [3], minimizing the total of purchasing, inventory, transportation, and supplier management costs [4], minimizing the total of selecting, procuring, holding, and shortage costs [5]. Another methods considering multi-objective have also been developed, such as multi-objective mathematical model which minimize total cost and maximize total social, total environmental, and total economic qualitative scores [6], multi-objective mixed integer non-linear programming (MINLP) model which considered cost, quality and service level [7,8]. and a hybrid of the DEA, fuzzy multi-objective programming and genetic algorithm [9].

The purpose of the study is to create an optimization model to determine the allocation of orders to a number of suppliers, where there are three important issues to be decided. These three issues comprise of determining the ability level of each supplier to meet the criteria set by the buyer, determining the quantities of material to be ordered, and determining the ordering time to fulfil the needs.

This paper is organized as follows. A brief review of the literature is presented in section 2, while section 3 contains the research methodology. Section 4 and 5 contain a numerical example, the results, and the discussions, while the conclusions is presented in section 6.

2. Methods

To solve the integrated problem of supplier selection and order allocation, a comprehensive framework is proposed. The proposed approach presents two-stage decision making procedure, where AHP is applied in the first stage to evaluate the weight of each supplier performance, and a linear programming model is applied in the second stage to allocates order quantities between the suppliers. The proposed algorithm consists of the following steps:

1. Constructing a hierarchical system
2. Preparing a pair-wise comparisons matrix and perform the synthesis process.
3. Calculating the weights and testing the consistency ratio.
4. Computing the overall performance score of each supplier.
5. Constructing the linear programming model

2.1 Constructing the hierarchical system

Structuring a hierarchy/decision model, i.e. to construct hierarchies based on the objectives, criteria, sub-criteria and alternatives, so that the overall structure/decision model is visible.

2.2 Making pair-wise comparison and perform the synthesis process

As explained in Saaty [10], after the hierarchy has been structured, the next stage is to do a pair-wise comparison and provide judgement to the pair of criteria, sub-criteria, or alternatives using a basic scale (fundamental scale) 1 to 9. This assessment is done by comparing a number of combinations of components that exist at each level of the hierarchy, so that the quantitative analysis to determine the magnitude of the weight can be done.

2.3 Calculating the weights and testing the consistency ratio

Perform the normalization process, i.e. making the unit of each criterion, sub-criterion, or alternative to be the same, so that we can compare each criterion, sub-criterion or alternative. Then calculate the Consistency Ratio (CR) to determine the level of consistency of the decision maker in providing judgement. If the CR is $< 10\%$ then the decision maker is already consistent in doing their judgement

2.4 Computing the total performance score of each supplier

To determine the performance rating of each supplier, multiply the value of each sub criterion with the weight of that sub criterion, then sum that value to all criteria

2.5 Building the linear programming model

Construct a linear programming model using the suppliers' performance rating as the coefficient of the objective function to be maximized. The goal is to allocate the order quantities subject to some important constraints.

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3. Results and Discussions

The following illustration is intended to explain how the proposed model is used. Suppose that the constraints of this linear programming are buyer's demand, supplier's capacity, supplier's defect rate, and supplier's delivery reliability, then the objective function and constraints of this linear programming are as follows.

3.1 Notations

S_j final score of supplier j
V_j maximum quantity that can be supplied by supplier j
L_j lot-size of supplier j
D buyer's demand quantity
q_j percentage of defect rate of supplier j
Q buyer's maximum acceptable defect rate
r_j percentage of late delivery of supplier j
R buyer's maximum acceptable late delivery
X_j integer decision variable denoting the number of lots ordered from supplier j

3.2. The Objective Function

The objective function to maximize the total final scores of all suppliers can be shown as

$$Max \sum S_j X_j L_j \qquad j = 1, 2, ..., n \tag{1}$$

3.3. The Constraints

The important constraints of the problem are buyer's demand quantity, the quality, the delivery reliability, and the supplier's capacity, which are formulated as follows:

Demand constraint

The total order quantity of the item from all suppliers must meet the demand quantity of the item. It can be stated as

$$\sum X_j L_j \le D \qquad j = 1, 2, ..., n \tag{2}$$

Quality constraint

The total defect quantity of the item cannot exceed maximum total acceptable defect quantity, therefore,

$$\sum q_j X_j L_j \le QD \qquad j = 1, 2, ..., n \tag{3}$$

Delivery constraint

The total late delivery cannot exceed maximum total acceptable lateness. It can be stated as

$$\sum r_j X_j L_j \le RD \qquad j = 1, 2, ..., n \tag{4}$$

Supplier's capacity constraint

The order quantity of the item cannot exceed the supplier's capacity. It can be stated as

$$X_j L_j \le V_j \qquad j = 1, 2, ..., n \tag{5}$$

Non-negativity constraint

$$X_j \ge 0, \text{ integer} \qquad j = 1, 2, ..., n \tag{6}$$

3.4. Final Model

The final integrated linear integer programming model can be shown as

$$Max \sum S_j X_j L_j \qquad j = 1, 2, ..., n \tag{7}$$

Subject to:

$$\sum X_j L_j \le D \qquad j = 1, 2, ..., n \tag{8}$$

$$\sum q_j X_j L_j \le QD \qquad j = 1, 2, ..., n \tag{9}$$

$$\sum r_j X_j L_j \le RD \qquad j = 1, 2, ..., n \tag{10}$$

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$$X_j \, L_j \leq V_j \qquad j = 1, 2, \ldots, n \tag{11}$$

$$X_j \geq 0, \text{integer} \qquad j = 1, 2, \ldots, n \tag{12}$$

The objective function (7) is to maximize the total final scores of all suppliers. The constraint (8) stating that the total order quantity of the item from all suppliers must meet the demand quantity of the item. The constraint (9) stating that the total defect quantity of the item cannot exceed maximum total acceptable defect quantity. The constraint (10) stating that the total late delivery cannot exceed maximum total acceptable lateness. The constraint (11) stating the supplier's capacity constraints, while constraint (12) stating that the number of lots ordered has to be integer and non-negative value.

3.5. Numerical Example

Suppose a company wishes to place an order of 1200 pieces of particular item, for which four suppliers are available. Each supplier accepts orders in lot sizes that vary from supplier to supplier. The lot-size for supplier A, B, C, and D is 40, 70, 60, and 50, respectively. Each supplier can supply only a maximum quantity given by 800, 500, 600, and 900 units for supplier A, B, C, and D respectively. The previous record shows that the defect rate for supplier A, B, C, and D is 3%, 5%, 1%, and 6% respectively, while the record of on-time delivery for supplier A, B, C, and D is 93%, 98%, 85%, and 92% respectively. The company's maximum acceptable defect rate is 4% and the maximum acceptable lateness is 8%.

3.5.1 Supplier Selection. Suppose the company have found five most important criteria and 11 sub-criteria as shown in Table 1, that leads to the hierarchy structure of the problem as shown in Figure 1.

Table 1. The main-criteria and sub-criteria for performance evaluation

Main-criteria	Sub-criteria	Description
Purchasing Cost	Product price	Price offered by supplier
	Condition of payment	Date of maturity of the invoice
Product Quality	Defect ratio	Defective percentage rate
	Supporting document	All important documents are available
Delivery Reliability	On-time delivery	Goods are delivered as per PO date
	Delivery accuracy	Goods are delivered in accurate quantities
	Delivery time	Total time since order to delivery
Service	Responsiveness to request for quotation	Supplier promptly submits quotation after receiving a request for quotation
	Responsiveness to claim/problem resolve	Supplier quickly responses back when claim/problem is reported
Flexibility	Inventory availability	Supplier' ability to fulfill customer's demand
	Negotiability	Supplier' willingness to negotiate on price and delivery schedule

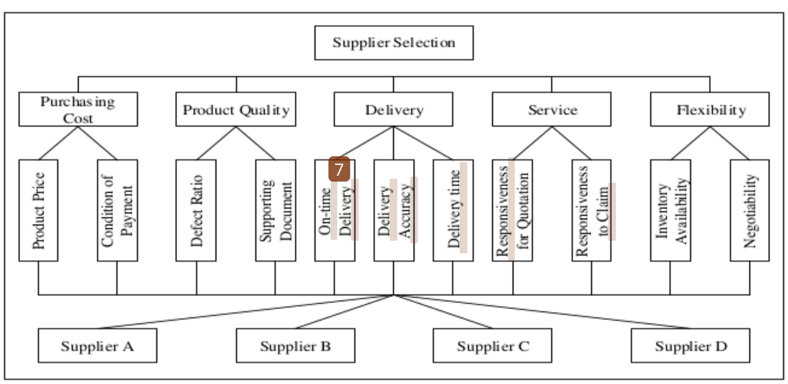

Figure 1. The hierarchical structure for supplier selection

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The input data consisting of pair-wise comparison matrix of the suppliers for the five main-criteria is given in Table 2.

Table 2. The pair-wise comparison for the five main-criteria

	Purchasing Cost	Product Quality	Delivery	Service	Flexibility
Purchasing Cost	1	1	3/2	2	2
Product Quality	1	1	3/2	2	2
Delivery	2/3	2/3	1	3/2	3/2
Service	1/2	1/2	2/3	1	3/2
Flexibility	1/2	1/2	2/3	2/3	1

For simplicity, let say that the sub-criteria product price is twice more important than the condition of payment, the defect ratio is three times more important than the supporting document, the responsiveness for quotation is 1.5 times more important than the responsiveness to claim resolve, and the inventory availability is twice more important than the negotiability, and the pair-wise comparison matrix for the sub-criteria of delivery is shown in Table 3.

Table 3. The pair-wise comparison for the five main-criteria

	On-time Delivery	Delivery Accuracy	Delivery time
On-time Delivery	1	3/2	2
Delivery Accuracy	2/3	1	3/2
Delivery time-cost	1/2	2/3	1

The pair-wise comparison matrices for each of 11 sub-criteria are shown in Table 4 to Table 8.

Table 4. Pair-wise comparison for the sub-criteria of purchasing cost

	Sub-criteria							
	Product price of supplier				Condition of payment of supplier			
Supplier	A	B	C	D	A	B	C	D
A	1	2	3/2	3	1	2/3	1/2	1/2
B	1/2	1	3/2	3/2	3/2	1	2/3	1/2
C	2/3	2/3	1	2	2	3/2	1	3/2
D	1/3	2/3	1/2	1	2	2	2/3	1

Table 5. Pair-wise comparison for the sub-criteria of product quality

	Sub-criteria							
	Defect ratio of supplier				Supporting document of supplier			
Supplier	A	B	C	D	A	B	C	D
A	1	4/3	3/2	2	1	1	1	1
B	3/4	1	2	5/2	1	1	1	1
C	2/3	1/2	1	3/2	1	1	1	1
D	1/2	2/5	2/3	1	1	1	1	1

Table 6. Pair-wise comparison for the sub-criteria of delivery

	Sub-criteria											
	On-time delivery of supplier				Delivery accuracy of supplier				Delivery time of supplier			
Supplier	A	B	C	D	A	B	C	D	A	B	C	D
A	1	2	2	3/2	1	1/2	2/3	1/3	1	2	3/2	4/3
B	1/2	1	1	2/3	2	1	3/2	2/3	1/2	1	2/3	2/3
C	1/2	1	1	2/3	3/2	2/3	1	1/2	2/3	3/2	1	2/3
D	2/3	3/2	3/2	1	3	3/2	2	1	3/4	3/2	3/2	1

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Table 7. Pair-wise comparison for the sub-criteria of service

	Sub-criteria							
	Responsiveness for quotation of supplier				Responsiveness to claim resolve of supplier			
Supplier	A	B	C	D	A	B	C	D
A	1	2	3	3	1	1/2	1/3	1/4
B	1/2	1	3/2	4/3	2	1	1/2	1/3
C	1/3	2/3	1	2/3	3	2	1	2/3
D	1/3	3/4	3/2	1	4	3	3/2	1

Table 8. Pair-wise comparison for the sub-criteria of flexibility

	Sub-criteria							
	Inventory availability of supplier				Negotiability of supplier			
Supplier	A	B	C	D	A	B	C	D
A	1	1/3	1/4	1/5	1	1/2	2/3	3/4
B	3	1	2/3	1/2	2	1	3/2	4/3
C	4	3/2	1	2/3	3/2	2/3	1	3/2
D	5	2	3/2	1	4/3	3/4	2/3	1

In order to determine the final score of each supplier, the AHP model is performed using *Expert Choice* software, where the result is given in Figure 2.

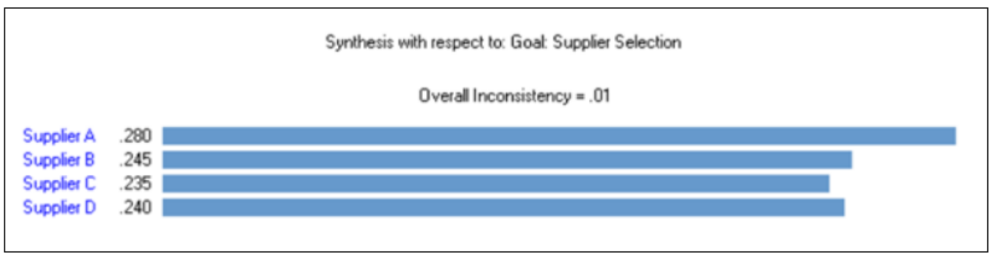

Figure 2. The final score of each supplier

3.5.2 Order Allocation
In order to find the best order quantities, the total final scores of suppliers should be maximized. The model formulation is as follows.

3.5.2.1 Objective function
The objective to maximize the total final scores of all suppliers is expressed as:

$$Max \quad 0.280\, X1 + 0.245\, X2 + 0.235\, X3 + 0.240\, X4$$

3.5.2.2 The demand constraint
The total order quantity of the item from all suppliers must meet the demand quantity of the item, therefore:

$$40\, X1 + 70\, X2 + 60\, X3 + 50\, X4 \leq 1200$$

3.5.2.3 The quality constraint
The total defect quantity of the item cannot exceed maximum total acceptable defect quantity, therefore:

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$(0.03 \times 40)\, X1 + (0.05 \times 70)\, X2 + (0.01 \times 60)\, X3 + (0.06 \times 50)\, X4 \leq (0.04 \times 1200)$
or $1.2\, X1 + 3.5\, X2 + 0.6\, X3 + 3\, X4 \leq 48$

3.5.2.4 The delivery constraint
The total late delivery cannot exceed maximum total acceptable lateness. It can be stated as:
$(0.07 \times 40)\, X1 + (0.02 \times 70)\, X2 + (0.15 \times 60)\, X3 + (0.08 \times 50)\, X4 \leq (0.08 \times 1200)$
or $2.8\, X1 + 1.4\, X2 + 9\, X3 + 4\, X4 \leq 96$

3.5.2.5 The supplier's capacity constraint
The order quantity of the item cannot exceed the supplier's capacity. It can be stated as

$40\, X1 \leq 800$
$70\, X2 \leq 500$
$60\, X3 \leq 600$
$50\, X4 \leq 900$

The problem is then solved using Linear Interactive Discrete Optimizer (LINDO) software, where the report is shown in Figure 3, where the solution gives an optimal order of 20 lots with supplier A and 8 lots with supplier D, and the total final scores is 7.52. No orders are placed with the supplier B and C.

```
MAX      0.28 X1 + 0.245 X2 + 0.235 X3 + 0.24 X4
 SUBJECT TO
        2)   40 X1 + 70 X2 + 60 X3 + 50 X4 <=   1200
        3)   1.2 X1 + 3.5 X2 + 0.6 X3 + 3 X4 <=   48
        4)   2.8 X1 + 1.4 X2 + 9 X3 + 4 X4 <=   96
        5)   40 X1 <=   800
        6)   70 X2 <=   500
        7)   60 X3 <=   600
        8)   50 X4 <=   900
 END
 GIN      4


LP OPTIMUM FOUND AT STEP      3
 OBJECTIVE VALUE =    7.51999998


       OBJECTIVE FUNCTION VALUE

       1)       7.520000

 VARIABLE         VALUE          REDUCED COST
       X1        20.000000          -0.280000
       X2         0.000000          -0.245000
       X3         0.000000          -0.235000
       X4         8.000000          -0.240000

      ROW   SLACK OR SURPLUS     DUAL PRICES
       2)         0.000000          0.000000
       3)        -0.000001          0.000000
       4)         8.000001          0.000000
       5)         0.000000          0.000000
       6)       500.000000          0.000000
       7)       600.000000          0.000000
       8)       500.000000          0.000000

 NO. ITERATIONS=        3
 BRANCHES=     0 DETERM.=   1.000E    0
```

Figure 3. Problem and solution report for the example

The numerical example demonstrates that the model offers a reasonable and realistic solution based on the imposed objective and constraints. The optimum solution shows that to obtain 1200 units of the demanded product, the company has to order 20 lots of product from supplier A which means that the quantity of product ordered from supplier A is (20x40) = 800 units. In addition, the company has to order 8 lots of product from supplier D, which means that the quantity of product ordered from supplier D is (8x50) = 400 units.

Since the company's maximum acceptable defect rate is 4% and the maximum acceptable lateness is 8%, then the total defect product has to be less than (0.04x1200) = 48 units and the total product with late delivery has to be less than (0.08x1200) = 96 units. From the optimum solution it can be resumed that the total number of defect products from both suppliers A and D is (0.03x800) + (0.06x400) = 48 units, which is equals to the company's maximum acceptable defect rate. The total unit of product that will be late delivered both from supplier A and D is (0.07x800) + (0.08x400) = 88 units, which is less than the company's maximum acceptable lateness.

4. Conclussion

The overall supplier selection problem of multiple sourcing is not only to select the right suppliers, but also to allocate optimal order quantity among the selected suppliers, based on a number of key criteria such as costs, quality, delivery reliability, supplier's capacity, etc. For these purposes, the two-stage decision making procedure was developed in this paper. Firstly, a hierarchical structure for supplier selection was developed through the analytical hierarchy process, in consideration of both quantitative and qualitative criteria, in order to identify a set of candidate suppliers. Secondly, to help management allocate the optimum order quantities to the candidate suppliers, a linear programming model was formulated such that the total final score of suppliers becomes maximum.

The advantage of this proposed model is that it can deal with multiple criteria, both qualitative or quantitative, such as cost, quality, delivery reliability, customer services, and many other criteria in supplier selection problems. For future research, this model can be extended by considering uncertainties, since many parameters may not be estimated certainly, such as customer demand and supplier's capacity.

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